Agent based coordinated job/shop scheduling in production processes

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Abstract: The coordination mechanism (CM) considers the multi agent system (MAS) approach, which yields the possibility of mutual communication among different agents representing the jobs or the production resources. This contribution deals with the creation of CM for the solution of job/shop scheduling problem in manufacturing production processes.

1 Introduction

The CM (economical and temporal) can use the sets of job agents and of resource agents. Suppose that each agent has individual properties which may be any constraints from the aspect of possible coordination and communication. Such scenario is an abstraction of many real world scenarios in manufacturing and logistics where the number of job agents compete for the achieving of available production agents (resources). In this case the agents are independent in their decision but have information about other agents. Such situation can be found e.g. in flexible manufacturing systems, supply chain performance, power engineering, telecommunication, etc.. In such systems the conflict cases can appear where the problem of optimal planning of jobs performance or of production resources scheduling must be handled. To handle such problems the MAS approach might be very suitable which provides the following possibilities:

- modeling of tasks, production resources, management etc. on the basis of agent rules or rules of agent coalition
- determination of criteria for the evaluation of agents or agents coalition performance
- utilization of negotiation process for the determination of the performance effect from the aspects of given requirements, constrains, etc.

The coordination mechanism (CM) created on the MAS basis given above is the available tool for the solution of the problems given above. The solution of such problems is the subject of many publications [1] [2] [3].

2 The scheduling problem formulation

Scheduling is defined the as assigning the given job to such device which is able to perform it effectively. In other words, the problem is to create effective jobs/devices pairs. Because the job performance is realized by operations on the production device, the solution of the scheduling problem can be extended to the schedule of the triplet job/ device/ operation (SJDO). The formulation may be as follows:

Formulation 1: SJDO consists of a set $M=\{1,...,m\}$ of m devices; a set $J=\{1,...,n\}$ of n jobs and of set $O_j = \{\{o_j^1,...,o_j^{nj}\}$ of n_j operations. For each operation o_j^i on the machine $m_j^i \in M$ a processing time $t_j^i \in T$ is given. Ready time $r_j \in T_0$ denotes the earliest possible time for the first operation of each job $j \in J$. Then we can express the performance of the job symbolically by the relation

$$(r_j ,[(m_j^1, t_j^1),..., (m_j^{nj} , t_j^{nj})]) \tag{1}$$

Let us consider two types of scheduling:

- *a potential scheduling for a set of operations* is a mapping from the operations to start times; the potential schedule which assigns the start times to all operations in T is called complete
- *a potential schedule is called feasible if*:

a. no first operation starts early

b. no sequence constraint is violated

c. no overlap in the processing time of assigned operations occurs on any machine.

The combination of the complete and feasible schedule is denoted as a validated schedule (VS), which may be formulated as follows:

Formulation 2: $\cup_{j\in J} O_j \rightarrow T_0$ is suitable schedule if:

– $o_j^1 \geq t_j$ for all $j \in J$

– $s (o_j^i) + t_j^i \leq s (o_j^{i+1})$ for all $j \in J$ and all $i \in (1,...,n_{j-1})$

– for each pair of different operations $o_j^h ; o_k^i$ where is either $m_j^h \neq m_k^i$ or $s(o_j^h) + t_j^h \leq$

$s(o_k^i)$ or $s(o_k^i) + t_k^i \leq s(o_j^h)$; j , $k \in J$; $h \in \{1,...,n_j\}$; $i \in \{1,..,n_k\}$; if $j = k$; $h \neq I$

3 The economical problem of scheduling

Formulations 1 and 2 suppose the scheduling in time domain. The next step is to extend the scheduling to the economical cases too. This assumes competition of the jobs to get the most suitable resources (devices) for their performance. For the solution of this problem we introduce an objective function as follows: $v_j^i : S \rightarrow T_0$ is an available schedule (*S*), if for every job agent a nonnegative value is assigned to each possible VS. The formulation of economical SJDO, i.e ESJDO may be as follows:

Formulation 3: SJDO and a set of *j* value functions $V = \{v_1', ..., v_j'\}$, where each element coresponds to one job $j \in J$; $v_j' : S \rightarrow T_0$ expresses a set of all completed schedules which solve the given task in time domain. The general purpose of ESJDO is to select from all possible schedules such on which gives the economical efficiency and is expressed by the relation:

$$\arg \max_{s \in S} \sum_{j \in J} v_j'(s) \tag{2}$$

For the solution of (2) the following procedure can be considered:

Let us consider the valuable schedule in time domain so that we begin with the earliest operation of job 1 until its completion. Then let us continue with operations of job 2… until all operations, are scheduled. according to the criterion (3).

$$\min C^{max} = \max_{j \in J} C_j \tag{3}$$

where $C_j = s(o_j^{nj} + t_j^{nj})$ is the completion time of the last operation of job *j* in the valuable schedule *s*.

Let us determine by the value function $v_j'(s)$ of each job *j* the value of the valuable schedule efficiency with consideration of the first step results. This condition can be expressed by the relation :

$$s(o_j^{nj} + t_j^{nj}) \rightarrow C_j \tag{4}$$

Proposition 1 : A schedule maximizes the economic efficiency (2) over all schedules in *S* if and only if it minimizes the sum $\Sigma^n_{j=1} C_j$ of total completion time over all schedules in *S*.

This procedure will be used in the negotiation process.

4 The possible application of the negotiation process

On the basis of the considerations introduced in sections 2 and 3 above the requirement of optimal schedule should be formulated as a competition of agents. For example, the of job agents (AJ) compete to attain the most suitable device agents (AD) for their realization. From a different aspect it is possible to consider that each AD competes to attain such job which is more suitable from the economical aspect. To solve the problem formulated as above, the negotiation process (NP) can be used with a following sets of agents:

set of n AJ agents $N = J = \{1,\dots,n\}$

set of m AD agents $\Omega = M = \{1,\dots,m\}$

set of l agents which express the criteria AV ; $V = \{1,\dots,l\}$. They could be considered as the attributes.

In the NP, the argumentation plays a very important role. It expresses the properties of agents for the determination of the preferences. The final result of the NP within the sense of AV is the alternative solution of the above problem with the best preference. Then it is the most suitable pair AJ and AD within the meaning of v_j^m.

We suppose that the agents have two types of knowledge:

knowledge of the evaluated alternative for the solution of given problem according to more criteria

knowledge of the argument set $g_i \in G$, which are used in the NP.

Let we define the available alternatives $A = \{a_1,\dots,a_k\}$ as penetration of sets:

$$A = N \cap \Omega \cap AV \quad (5)$$

Let us define the optimal alternative within the meaning of Bellmann principle: the alternative solution of each agent is optimal if the whole solution is optimal.

Despite that each agent prefers the proper goal according to the Bellmann principle, the optimal solution of the complex task requires a compromise as the result of the NP formulated as follows:

$$A' \subset A \; ; M' \subset M \; ; V' \subset V \quad (6)$$

then $$A' = J' \cup M' \cup V'$$

Then, in the scheduling procedure the following assumptions have to to be considered :

- it is required that the performance of the agents participating in the solution of given task is optimal

– a global criterion of agent coalition (CA) performance Q is given as the a sum of the AJ performance criteria q_i

– on the beginning of the solution procedure each agent has a proper alternative solution $a_i \in A$.

5 Logical and mathematical formulation of the problem

On the basis of the strategies and assumptions introduced in previous parts the logical and mathematical formulation of the above problem may be as follows:

Let us have n agents $Ag_i \in AU$ $i= 1,2,...,n$

Let us consider not more then m possible alternatives $a_j \in A$, $j =1,2,..,m$ which, together with the arguments $g_i \in G$ create the preferred suggestion of solutions P_k $k=1,2,...,l$ from the aspect of relevant agent criterion.

The arguments contain the agent criterion q_i and the elements of the sets of weight obtained from the evaluation of alternatives according to Q and $v_j \in V$. Then P_k can be defined by the relations :

$$P_k = (a_j ,v_i) \tag{7}$$

$$g_i = (q_i , f (q_i ; v_i .a_j)) \tag{8}$$

where

f – may be some function consisting of the user requirements.

Within the sense of (7) (8) each agent determines the weight and then also the order of alternatives (from the set of alternatives enabling to solve the global task $GT= \{gt_1, ...gt_h\}$.

Let CA for the solution of GT be expressed by the relation :

$$CA = \bigcup_{i=1}^{n} Agi \tag{9}$$

Let the global criterion of CA performance be given by

$$Q = \sum_{i=1}^{n} q_i \tag{10}$$

where

$$q_i = f (x, y, z) \tag{11}$$

is the local criterion of agents as a function of *x,y,z* variables which express the characteristics of concrete jobs performed by relevant agents.

The objective of the solution is to determine max. Q or min. Q using the chosen alternatives progressively (the effort of each agent is to prefer its own goal). This is expressed mathematically by weighting own criterion. The value of the preferred agent criterion is the bigger then the values of other agents criteria. The result of such solution procedure is then:

$$a_{ii} \succ a_{i,i+1} \succ ...... \succ a_{i,m} \qquad Q_{i,i} > Q_{i,i+1} > .... > Q_{i,m} \tag{12}$$

and then

$v_{i,i} > v_{i,\, i+1} > ...... > v_{i,m}$ ($a_i \succ a_{i+1}$ denotes that a_i is preferred to a_{i+1}).

For this case the Bellmann principle can be expressed as follows: each *CA* works optimally if whole solution performed by *CA* is optimal.

6 Strategy of the iterative algorithm

Let us consider a progressive decision process which uses the NP rules of MAS for the choice of optimal alternative which gives the optimal solution of the given task in the sense of (7)(8)(9)(10)(11). We suppose that for the solution of given requirement *pv* all alternatives from $A_i = (a_1,...,a_m)$. progressively. For example, if

- A_1 is an ordered set of agents Ag_1..., etc., the space of alternatives is a Chartesian product of alternative sets:

$$A = A_1 \, x \, A_2 \, x...x \, A_k \tag{13}$$

The basic function F containing the set of agents Ag, set of associated alternatives A, objective function Q and requirements pv can be expressed symbolically as follows:

$$F = F\,(Ag, A, Q, pv) \tag{14}$$

The rule of the NP is to determine optimal (suboptimal) strategy which contains the chosen and ordered (by the winner agent) alternatives:

$$\pi^* = (a_1^*,..., a_m^*) \tag{15}$$

For the determination of π^* let us apply the Bellmann principle; then the iterative procedure has 4 steps.

Step 1: For the fulfilment of given requirement *pv max. Q* is calculated according to the variables *x, y, z* by combination of all alternatives and agents where each agent prefers the proper *q*. The preferences are expressed by relevant weight.

Step 2: On the basis of agent arguments according to step 1 (vq_i , Q_i (a_i)) *the sequence* max.(min) Q_i (a_i) *is determined in the NP:*

$$Q_2 (a_1) > Q_3 (a_2) > ...> Q_n (a_m) \tag{16}$$

Step 3: On the basis of e.g. $maxQ_i$, obtained with the alternative $a_i \in A_i$ of agent *Ag* in the framework of *CA,* the agent winning by its alternative is determined

Step 4: On the basis of step 3, in the sense of the Bellmann principle, the alternatives of other agents of their for the solution own tasks are determined by reverse way.

The choice determined as above is a collective procedure with

$$\binom{n}{n-1}$$

combinations for the solution of the given task and requirements, and this is the strategy π^*. In the case of changes of any assumption or argument the whole iterative process must be repeated.

7 Case study

With respect to the previous parts, in SJDO and ESJDO our considerations will be focused to the optimal cooperation among AJ and AD (9). Then the global objective function *Q* according to formulations 1, 2, 3 consist of two parts. The first part expresses SJDO where the minimal performance time of the job is searched, and the second part expresses ESJDO, where the maximal economical effectiveness. This is a *min.max* solution way. On the other hand, if we consider the value of is searched effectiveness of the minimal cost of the job performance which depends on the number and time of operations, then with respect to proposition 1, *Q* is expressed by:

$$Q = \sum_{j=1}^{n} C_j \tag{17}$$

The NP according to (6) and to arguments *g* chooses relevant pairs. The final result of NP is given by alternatives :

$$a_1 \in A_1 \ ; a_2 \in A_2 \ ; ...,a_k \in A_k$$

We get the optimal strategy (15) by the comparison of the alternatives in the sense of (12) (16)(17).

For the verification of the scheduling procedures SJDO and ESJDO the fictive dates of AJ, AD and *pv* are considered.

A numerical example:

Let's have 5 jobs, each has some operations. Job shop consists of 4 machines. Le's assume that each operation can be processed on any of the machines. Each machine is given data (processing time and cost of operation).

Job 1 – consists of 4 operations

	Operation 1		Operation 2		Operation 3		Operation 4	
	Processing time	Cost (EUR)	Processing time	Cost (EUR)	Processing time	Cost (EUR)	Processing time	Cost (EUR)
Machine1	2	5	3	6	1	2	2	4
Machine2	2	5	2	4	1	2	1	4
Machine3	1	5	2	5	1	3	1	3
Machine4	2	6	2	5	2	3	2	5

Job 2 – consists of 2 operations

	Operation 1		Operation 2	
	Processing time	Cost (EUR)	Processing time	Cost (EUR)
Machine1	2	4	1	3
Machine2	2	5	2	5
Machine3	1	4	1	2
Machine4	3	6	2	4

Job 3 – consists of 2 operations

	Operation 1		Operation 2	
	Processing time	Cost (EUR)	Processing time	Cost (EUR)
Machine1	2	4	3	5
Machine2	3	6	2	4
Machine3	3	5	3	4
Machine4	2	5	3	5

Job 4 consists of 3 operations

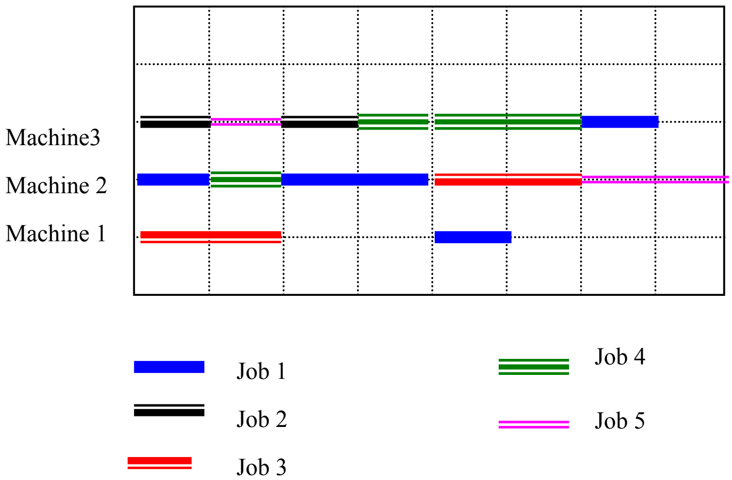
	Operation 1		Operation 2		Operation 3	
	Processing time	Cost (EUR)	Processing time	Cost (EUR)	Processing time	Cost (EUR)
Machine 1	1	2	2	3	2	4
Machine 2	2	2	1	2	2	4
Machine 3	1	2	1	2	2	4
Machine 4	1	3	2	2	3	4

Job 5 consist of 2 operations

	Operation 1		Operation 2	
	Processing time	Cost (EUR)	Processing time	Cost (EUR)
Machine 1	2	3	3	5
Machine 2	2	5	2	3
Machine 3	1	2	3	3
Machine 4	2	3	2	5

In the first step an evaluation, according SJDO is processed and alternatives are then evaluated according ESJDO is performed.

Fig.1: Final schedule



Results for scheduling obtained by applying the above described methods SJDO, ESJDO:

	Operation 1				Operation 2				Operation 3				Operation 4			
	M	t [min]	Start T [min]	Cost [EUR]	M	t [min]	Start T [min]	Cost [EUR]	M	t [min]	Start T [min]	Cost [EUR]	M	t [min]	StartT [min]	Cost [EUR]
J1	2	1	0	5	2	2	2	4	1	1	4	2	3	1	6	3
J2	3	1	0	4	3	1	2	1								
J3	1	2	0	4	2	2	4	2								
J4	2	1	1	2	3	1	3	2	3	2	4	4				
J5	3	1	1	2	2	2	6	3								

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Conclusions

The paper introduces coordination mechanisms for production scheduling using MAS and applying economical criteria for negotiation. The advantage of applying economical criteria is in market oriented production. However economical criteria are related to the time criteria, it is important for design MAS to implement these criteria and change agents behavioue for negotiation. The future development is oriented on application of presented results.

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